## IN THE DRAWINGS

Please add FIGs. 7-9 filed concurrently with this preliminary amendment.

## IN THE ABSTRACT

Please delete the ABSTRACT and replace it with the following.

--An amplifier (170) includes first and second depletion mode transistors (161, 162) operating in response to first and second complementary signals ($V_{AMP+}$, $V_{AMP-}$), respectively, which route a first current ($I_{STACK1}$) from a first supply terminal (171) to an output (169) of the amplifier. Third and fourth depletion mode transistors (163, 164) receive the first and second complementary signals to route a second current ($I_{STACK2}$) from a second supply terminal (Ground) to the output. The first and second currents are summed to produce an output signal ($V_{AMP2}$).--

## IN THE SPECIFICATION

Please add the following sentence as the first paragraph following the title.

--The present application is based on prior U.S. application No. 09/580,560, filed on May 30, 2000, which is hereby incorporated by reference, and priority thereto for common subject matter is hereby claimed.--

Please change the title from "LOW VOLTAGE OUTPUT DRIVE CIRCUIT" to "LOW VOLTAGE AMPLIFYING CIRCUIT".

Please delete the text from page 1, line 6, through page 3, line 30 and replace with the following.

--The present invention relates in general to electronic circuits and, more particularly, to amplifying circuits that operate at low supply voltage levels.

As integrated circuits achieve higher levels of integration, there is a corresponding need to operate the circuits at reduced voltage levels in order to maintain power dissipation at manageable levels. For example, it is anticipated that future microprocessors and other digital circuits will need to operate with power supply voltages of 0.5 volts to maintain an acceptable die temperature. Future circuits are expected to operate with even lower supply voltages.

A low supply voltage typically is produced by a voltage regulator implemented as an integrated circuit. The regulator includes an error amplifier to sense the supply voltage and feed back an error signal that adjusts the voltage level to maintain regulation. The error amplifier and its associated circuitry preferably also operate at a low voltage in order to achieve a low power dissipation by the regulator circuit.

Most if not all integrated circuit amplifiers operate only at supply voltages that exceed the conduction threshold of the integrated circuit's transistors. When the supply voltage drops below the conduction threshold level, the transistors cease to function and gain of the amplifiers drops quickly to zero. In a case where the amplifier is being used in a voltage regulator, the rapid loss of gain can cause the regulator's output voltage to transition out of its specified range, which can damage both the regulator and the circuits operating from the regulator's output supply voltage.

Accordingly, there is a need for an amplifier circuit and method of amplifying that maintains functionality at lower

supply voltages than what is currently available.—

Please remove the paragraph from page 4, lines 4-15 and replace with the following.

--FIG. 1 is a block diagram of a supervisor circuit and microprocessor;

FIG. 2 is a waveform plot of an output signal of a prior art supervisor circuit;

FIG. 3 is a waveform plot of an output signal of a supervisor circuit;

FIG. 4 is a schematic diagram of a trigger circuit of the supervisor circuit;

FIG. 5 is a block diagram of a prior art linear regulator circuit;

FIG. 6 is a block diagram of a first regulator circuit;

FIG. 7 is a schematic diagram of a second regulator circuit including an amplifier;

FIG. 8 is a schematic diagram of the amplifier; and

FIG. 9 is a schematic diagram of an alternate embodiment of the amplifier.—

Please insert the following text after page 12, line 17.

--In the following figures, elements having the same reference numbers have similar functionality.

FIG. 7 is a schematic diagram of a voltage regulator 100, including an amplifier 102, transistors 104 and 106, resistors 108 and 110 and capacitors 112 and 114. Voltage regulator 100 receives an input supply voltage $V_{SUPP}$ on a supply terminal coupled to a node 118 and produces a regulated voltage $V_{REG}$ at an output 120. Regulator 100 is suitable for integrating on a semiconductor die to form an integrated voltage regulator circuit.

Resistors 108 and 110 are scaled to a predetermined ratio

and serially coupled between output 120 and ground potential
to function as a voltage divider that monitors or senses
regulated voltage $V_{REG}$ and provides a divided sense voltage
$V_{SENSE}$ on a node 122.

Amplifier 102 comprises a differential input-differential
output voltage or transconductance amplifier configured to
operate from supply voltage $V_{SUPP}$ at values approaching zero
volts.  In one embodiment, $V_{SUPP}=0.3$ volts.  An inverting input
is coupled to node 122 to receive sense voltage $V_{SENSE}$ and a
non-inverting input at a node 124 receives a reference voltage
$V_{REF1}$.  An error voltage $V_{ERR}=(V_{REF1}-V_{SENSE})$ applied across the
inverting and non-inverting inputs is amplified to produce a
differential output signal $V_{AMP}=(V_{AMP+}-V_{AMP-})$ across output nodes
128 and 126, where $V_{AMP-}$ and $V_{AMP+}$ are the component signals of
$V_{AMP}$ and have opposing phases.

The transient characteristics of amplifier 102 are a
function of the impedances of nodes 126 and 128, which are
determined by loop stabilization capacitors 112 and 114 and
the gate capacitances of transistors 104 and 106, and
therefore are highly capacitive.  Accordingly, the output
stage of amplifier 102 is configured to drive nodes 126 and
128 with currents high enough to meet specified transient
response characteristics and low enough to ensure loop
stability under the specified operating and environmental
conditions of regulator 100.

Transistors 104 and 106 are formed as metal oxide
semiconductor field effect transistors (MOSFET) operating in
the depletion mode.  Transistor 104 is an n-channel MOSFET
while transistor 106 is a p-channel MOSFET as shown in FIG. 7.
Transistors 104 and 106 are serially coupled between input
120 and output 118, with their sources being commonly coupled
to a node 127 to function as a pass element of regulator 100.
Because transistors 104 and 106 are formed as series coupled
depletion mode devices, their conduction thresholds are
negative, so they are conductive even with zero volts of gate

to source bias potential. As a result, regulator 100 is able to maintain regulation when the input-output voltage differential ($V_{SUPP}$-$V_{REG}$) approaches zero volts. In one embodiment, input-output voltage differential ($V_{SUPP}$-$V_{REG}$) is 0.2 volts. In one embodiment, transistors 104 and 106 are formed to have typical conduction thresholds of -0.2 volts, thereby providing conduction at zero volts of gate to source potential.

In operation, assume that $V_{SUPP}$=0.3 volts, $V_{REF1}$=0.125 volts and $V_{REG}$ initially is zero, with a target value of 0.25 volts. Further assume that the resistances of resistors 108 and 110 are equal, so $V_{SENSE}$=$V_{REG}$/2. Since $V_{REG}$ is zero, $V_{SENSE}$ is zero as well, and therefore less than $V_{REF1}$, so $V_{AMP-}$ decreases while $V_{AMP+}$ increases, turning on transistors 104 and 106 to couple a current $I_{LOAD}$ from input 118 to output 120 to charge an external load capacitor 130 to increase the value of $V_{REG}$. $I_{LOAD}$ continues to flow until $V_{REG}$ reaches its target value of 0.25 volts, at which time $V_{SENSE}$=$V_{REF1}$=0.125 volts, approximately. While $V_{REG}$ is at its target value, amplifier 102 controls the conduction of transistors 104 and 106 such that $I_{LOAD}$ flows at a level sufficient to supply the current requirements of the load circuitry (not shown) operating from $V_{REG}$, thereby maintaining regulation. In one embodiment, regulator 100 is configured to supply $I_{LOAD}$ to a magnitude of one hundred milliamperes.

Under normal conditions $V_{REG}$ does not exceed its target value, but load switching or system noise may result in momentarily increasing $V_{REG}$ to a value greater than the 0.25 volt target value. If that occurs, amplifier 102 produces values of $V_{AMP+}$ and $V_{AMP-}$ that reduce the conduction of transistors 104 and 106 to allow the flow of current to the load circuitry to be supplied from charge stored on capacitor 130 until $V_{REG}$ decays to its target value.

FIG. 8 shows a schematic diagram of amplifier 102 in further detail, including depletion mode MOSFETs 140-144.

Transistor 140 is an n-channel device whose gate and source operate at ground potential to function as a current source that supplies a bias current $I_{BIAS}$ to a common node 145. Transistors 143-144 are p-channel devices whose sources and gates are coupled to node 118 to function as current sources or high impedance loads that provide amplifier 102 with a high open loop gain. Alternatively, high impedance resistors or other types of devices can be used to perform functions equivalent to those performed by transistors 140 and 143-144. However, such alternative devices have the disadvantage of consuming a larger area of a semiconductor die, and therefore have a higher cost, than transistors 140 and 143-144.

Transistors 141-142 are configured as a differential pair receiving $V_{SENSE}$ and $V_{REF1}$ as a differential input signal that routes $I_{BIAS}$ through transistors 143 and 144 to produce component differential signals $V_{AMP+}$ and $V_{AMP-}$ of differential output signal $V_{AMP}$. Nodes 126 and 128 are relatively high impedance nodes which allow amplifier 102 to be easily compensated by capacitors 112 and 114 (shown in FIG. 7) when operated in a closed loop condition such as that of regulator 100.

The use of depletion mode devices for transistors 140-144 maintains their conduction and allows amplifier 102 to function at values of supply voltage $V_{SUPP}$ that approach zero. Accordingly, amplifier 102 is well suited for low voltage applications such as in regulating the supply voltage of a low voltage microprocessor. Although amplifier 102 is shown and described as being used as an active component of voltage regulator 100, it is evident that amplifier 102 is suitable for use in virtually any other analog application that would benefit from its economical structure and low voltage operation.

FIG. 9 shows a schematic diagram of an amplifier 170 receiving oppositely phased differential input signals $V_{IN+}$ and $V_{IN-}$ and producing a single ended amplified output signal $V_{AMP2}$

at an output 169. Amplifier 170 is coupled to a supply
terminal 118 to operate from a supply voltage $V_{SUPP}$. Amplifier
170 includes depletion mode MOSFET transistors 140-144 and
161-164 and a level shift circuit 133, and is suitable for use
as a low voltage amplifier in an analog amplification
application such as an error amplifier in a voltage regulator.

In an alternate embodiment, amplifier 170 is configured with
a high transconductance or voltage gain for use as a
comparator.

Transistors 140-144 function as a first or input stage of
amplifier 170 and operate in a fashion similar to that
described in the description of FIG. 8. Consequently, the
first stage has the benefit of operating at values of $V_{SUPP}$ that
approach zero.

Level shifter 133 level shifts component differential
signals $V_{AMP+}$ and $V_{AMP-}$ to produce level shifted signals $V_{LS+}$ and
$V_{LS-}$ on node 131 and 129, respectively. $V_{LS+}$ and $V_{LS-}$ retain the
information contained in $V_{AMP+}$ and $V_{AMP-}$ but are level shifted by
a DC voltage in order to bias transistors 161-164 for the
desired operation. For example, if class A operation is
desired, the level shifting DC voltage may be set to one-half
the value of supply voltage $V_{SUPP}$. Other level shifting
voltages may be used to provide other classes of operation.

Transistors 161-164 function as a second or output stage
of amplifier 170 whose operation is described as follows.
Transistor 161 is an n-channel device controlled by component
signal $V_{LS-}$ to set the conduction between supply terminal 118
and a node 166. Transistor 162 is a p-channel device
controlled by component signal $V_{LS+}$ to set the conduction
between node 166 and output 169. The conduction of
transistors 161-162 determine the level of a current $I_{STACK1}$
that is routed from supply terminal 118 to output 169 as a
first component of output signal $V_{AMP2}$.

Transistor 164 is a p-channel device controlled by
component signal $V_{LS-}$ to set the conduction between ground

potential and a node 168.  Transistor 163 is an n-channel
device controlled by component signal $V_{AMP+}$ to set the
conduction between node 168 and output 169.  The conduction of
transistors 163-164 determines the level of a current $I_{STACK2}$
that is routed from ground to output 169 as a second component
of output signal $V_{AMP2}$.

Output voltage $V_{AMP2}$ is developed from an output current
$I_{OUT}$ that flows from output 169 to a load 180 as the difference
between currents $I_{STACK1}$ and $I_{STACK2}$.

It can be seen that the present invention provides an
amplifier that occupies a small die area and has a low cost
while operating with an input-output voltage differential
approaching zero volts.  First and second depletion mode
transistors operate in response to first and second signals,
respectively, to route a first current from a first supply
terminal to an output of the amplifier.  Third and fourth
depletion mode transistors operate in response to the first
and second signals to route a second current from a second
supply terminal to the output.  The first and second currents
are summed to develop an output signal at the output.  The
negative thresholds inherent in depletion mode transistors
ensures active functionality with zero volts gate to source
potential, which allows the amplifier to function at very low
supply voltages, even approaching zero volts.  The first or
second signal can be coupled to a reference voltage to operate
the amplifier as a voltage regulator.--